ENVIRONMENTALLY ACCEPTABLE DISPOSAL OF MUNITION AND EXPLOSIVES

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Summary.

Conventional methods of disposing of munition and explosives such as dumping at sea and open-pit burning can no longer be tolerated in view of new environmental protection laws. Therefore TNO has investigated some alternative methods of disposal such as chemical treatment, bio-degradation and controlled burning.
Our investigations showed that controlled burning is the most applicable and promising technique. A closed furnace system is used for controlled burning. We can discriminate between rotary retort furnace, fixed grid furnace and fluidized bed furnace. The advantages and disadvantages of the different systems are given. The fluidized bed furnace seems the most suitable for the situation in the Netherlands.
Connected to controlled burning is the disassembly of medium and large calibre munitions.
Many techniques are available, for example punching, shearing, sawing, and cutting. We obtained very good results using a water jet. Because all possible munition articles can be opened in a short time, it is a very safe method and the explosive can be subsequently washed out and made into a slurry. This slurry can be pumped into the fluidized bed furnace.
Additional scrubbing systems (dry chemical/wet) are needed to remove the remaining hazardous products such as HCl, SO_2, NO_x.
Calculations for a complete disposal unit have been made.

1. Introduction.

Explosives are the active constituents in munition; their stored chemical energy can be used at the right time and place by means of the unique functioning of the munition fusing system. The characteristic reactions of explosives result in high reaction rates and high pressures. This causes a continuous threat to the environment regarding explosion safety, as munition may react accidentally due to heat, friction, shock and fragment or bullet impact. Because of this, munition must be disposed of at the end of its lifetime.

Munition was often disposed of by dumping it at sea. However, more recently disassembly and subsequent burning was used. These techniques pollute the environment and are therefore no longer acceptable. New techniques such as chemical and biochemical treatment were investigated in the laboratory; the state of the art of this research is briefly described. The most suitable disposal method is controlled burning. Special attention will be focused on the rotary retort furnace and the fluidized bed furnace.

As burning explosives produces many toxic gases there will be a need for specific measurements for the decomposition or the absorbance of these gases. Addition of catalysts, wet and dry scrubbers will be an integrated part of the disposal facility for munitions.

Finally some calculations are made to compare the costs of the different systems.

2. Quantitative description of the problem

Only a small amount of the in-service munition is used during exercises: most munition will remain in storage for its entire lifetime. This period can extend over 30 years.
Due to the recent political developments in Europe, an extra amount of munition has become superfluous.
A second source of munition and explosives is the World War II items still found daily in extensive numbers in the Dutch soil. An added problem here is the bad condition of these items; they may be severely damaged, the explosive may even be mixed with soil.
A third source is formed by out-of-date explosives from industry, or industrial intermediate compounds with explosive properties, and explosives or articles filled with explosives confiscated by the authorities (e.g., illegal fireworks).

Table 1. Annual amounts (kg) of regular explosives to be disposed of by the Dutch Army, Navy and Air Force

Explosive	Army	Air Force	Navy
Propellants	10700	800	5800
High explosives	150	5700	1200
Pyrotechnics	40	460	950

Table 2. Annual amounts (kg) of explosives and munition from WW II and out-of-date industrial explosives and fireworks

Fireworks	42000
Contaminated waste	200000
Fuses	20000
Small calibre munition	20000
Medium calibre munition	3000
Large calibre munition	30000
Bombs/mines	25000
Rockets	10000
Bare explosives	30000

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3. Methods of disposal

Dumping

The most common way to dispose of obsolete munitions was to dump them in isolated areas, preferably into deep trenches in the sea. The explosion risk will be minimized as the number of necessary munition handling steps is limited. It is obvious that dumping is a temporary and short-sighted solution to the problem; sooner or later we will be confronted with the consequences. The metal parts can react slowly with the environment and eventually the explosive and toxic contents will leak into the water. Pieces of munition can be picked up by fishermen, causing casualties. People bathing in the sea are at risk of being contaminated with chemical agents such as mustard gas.

Open-pit burning

A better solution to the problem is the more elaborate treatment of munition by dismantling and consequent burning of the explosive materials. The grenades can be separated easily from the cartridges; the propellant can be collected, the grenades defused and the explosives can be melted out if TNT or TNT-bases are involved.

The collected explosives, propellants and pyrotechnics are burned separately and in limited amounts in the open air, mostly at military proving grounds. This method is dangerous for the people in charge of the disposal and harmful to the environment. The toxic reaction product will pollute the air, soil and ground water.

The melting out of the explosives also results in water polluted with TNT which then has to be treated.

TNO has quantitatively studied the environmental burden as a result of open-pit burning in the Netherlands; this resulted in advising the Ministry of Defence to use a controlled burning facility, as the threshold values for many toxic components were exceeded, e.g., HCl, HF, Cl_2, SO_2, NO_x, lead, antimony, other heavy metals.

Bio-degradation

Several investigators have studied the possible use of micro-organisms, bacteria, to decompose the organic explosives (references 1, 2, 3, 4). The general conclusion from their work is that, in some cases, it is possible to decompose explosives to non-explosive components. However, these components are very toxic in the intermediate stages of decomposition (the formation of aromatic nitro-amines). Furthermore the decomposition is very slow and as such not suitable for treating large amounts of explosives.

Another problem is the diversity of the explosives present in munition and the various conditions in the soil (temperature, acidity, percentage of oxygen, other chemicals). Inorganic components cannot be treated in this way at all.

Further research will be necessary to turn bio-degradation into a fully applicable method to dispose of explosives.

Chemical treatment

This is in fact the reverse route from the synthesis of explosives. For some inorganic explosives this is the best and safest method to follow. A good example is the neutralization of Azides by treatment with $NaNO_2$. However the method is difficult to apply to organic explosives; it causes an explosion risk and, at the end, we have some toxic compounds which need further treatment. The best chemical reaction seems to be the treatment with excess oxygen at elevated temperature; this process is known as burning. A necessary condition is the possibility to control the time and place of burning. We call this controlled burning. As controlled burning is the most promising and complete technique, we will deal with this in more detail in section 5. A necessary condition for the controlled burning is the pre-treatment, we therefore give a short overview of the pre-treatment techniques.

4. Pre-treatment

Good separation of the explosive and the metal parts of the munition is mandatory for a more economic disposal procedure. In this way materials can be partly reused and the controlled burning will be more efficient.

Dismantling is the conventional pre-treatment of munition: it is the separation of the grenades from the cartridges and the collection of the explosives (see Open-pit burning).

Punching can be used for small pieces of munition with medium wall thicknesses. This method is used frequently to destroy chemical munitions.

Shearing is used to remove the fuse and booster from the grenades and to cut the rocket motor into smaller sections. The shearing is done with a guillotine-like shear blade.

Sawing or cutting is also used to open munitions.

Cryo-fracture works by cooling munition by immersing it in liquid nitrogen. At such a low temperature the metal from the grenades becomes brittle and can easily be crushed by hydraulic presses. The explosive and the metal parts can then be separated.

Water jet cutting is a powerful variance on the conventional metal cutting tools. Using a high pressure water jet and abrasive, metals can be cut at high speed. Nevertheless it is a relatively safe method as the water cools the metal and possible ignition of the explosive is suppressed.
At PML-TNO we opened all different types of munition successfully with this technique (see figures 1 and 2).

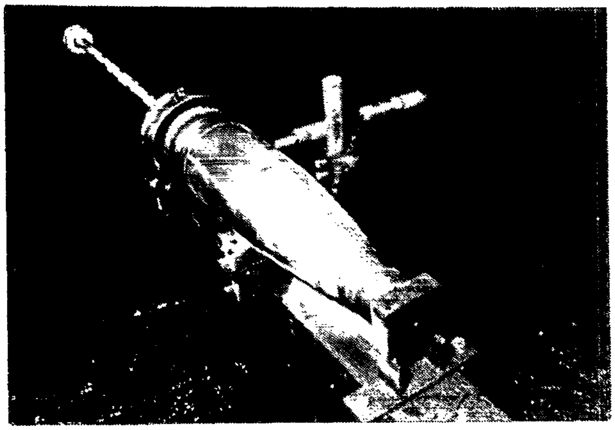

Figure 1. Test set-up for water jet cutting 155 grenade

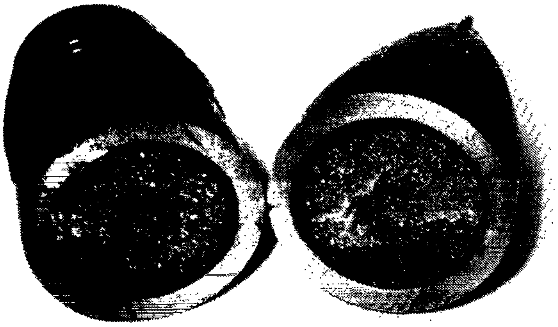

Figure 2. 155 grenade after water jet cutting

5. Controlled burning

The principle of controlled burning is the well-defined feed of munitions to a closed burning chamber or furnace. In this way the explosives can react with excess air to give the cleanest products. This, in connection with the further treatment of the reaction products, satisfies the threshold values defined in the National Environmental Protection Laws.

At the same time, the amount of explosives present in the furnace can be regulated to avoid pressures that can damage the furnace.
For controlled burning we can use three types of furnaces: rotary retort, fluidized bed, grid furnace.

Rotary retort
Controlled burning can best be described by looking at an existing system that was developed by the U.S. Army Ammunition Equipment Directorate in Tooele, Utah (see figure 3 and reference 5).

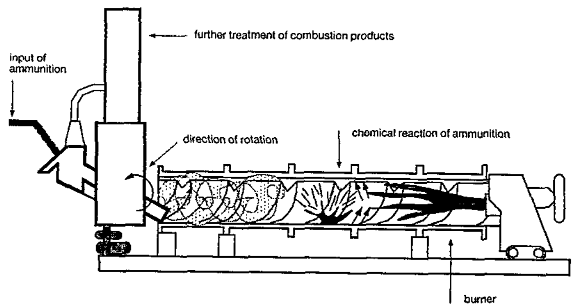

Figure 3. Principle of the Tooele Furnace

A conveyor belt transports the articles to the entrance of the furnace; from this point the munitions are transported by the spiral flight of the rotating furnace. On the other side of the furnace a burner is installed which can be fuelled by various means (fuel oil, natural gas).
Ignition will take place at a certain place as the munitions are transported towards the high temperature region of the furnace. At the end of the rotary retort the clean-burned metal pieces are transported on a conveyor belt to the metal dump.
Some disadvantages of the Tooele furnace are:
1. The reaction of the explosive is discontinuous in nature resulting in peak pressures disturbing the regular burning pattern. As a result, the residence time of the decomposition products in the afterburner is too short for complete clean combustion. Soot and even unreacted explosive will settle down in the cooler part of the exhaust system
2. The system can handle small amounts of fireworks and small calibre munition up to 20 mm. The larger calibres have to be opened to prevent the Deflagration to Detonation Transition (DDT).

Fluid bed
A fluid bed furnace uses a flow of hot air through a packed bed of silicon oxide particles.

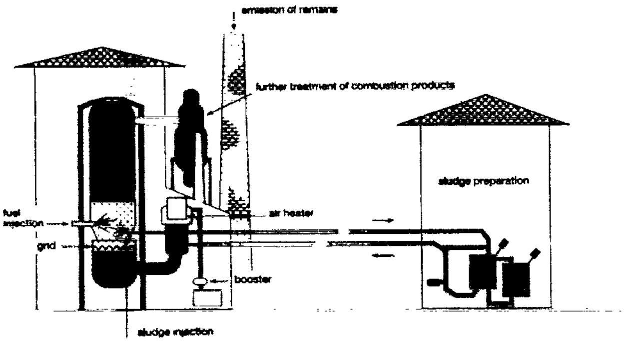

Figure 4. Principle of a fluid bed furnace

Due to the action of the air flow, the particles of the bed float and act as a liquid. The fuel is injected in or above this floating bed in the form of fine droplets, ensuring optimum mixing with air. Catalysts can be added to the bed tc facilitate the decomposition of explosives and to suppress the NO_x formation. For this reason fluid bed incineration has often been used for clean burning processes.

To be applicable for the disposal of munition, pre-treatment of the munition is mandatory. A combination with water jet cutting seems promising; the explosive is separated from the metal parts and ground to a slurry under water. The slurry is collected in a reservoir and transported to the furnace by pipes and injected in the bed.

Grid furnace

This type of furnace is used to dispose of domestic waste. The advantages are: flexibility and low cost.

Disadvantages: incomplete burning due to oxygen deficiency. Moving grid is vulnerable. Explosives can pass the grid without reaction. The latter phenomenon makes it unsuitable for the disposal of explosives.

6. Exhaust cleaning

We have seen that the solid reaction products can be collected in a cyclone or a bag house, while the gaseous products are emitted through the exhaust stack.

Explosives can react with oxygen producing harmless substances such as CO_2 and H_2O. However, depending on the composition of the explosive, there will be toxic compounds formed such as NO_x, CO, HCl, HF, SO_2. Research on a laboratory scale by ICT Germany (reference 6) has provided some data for the burning of the most common explosive materials.

Table 3. Gases formed during burning of explosives (w %)

Explosive	NO_x	HCl	SO_2	H_2S
Single base	10	-	-	-
Double base	19	-	-	-
TNT	0.01	-	-	-
Rocket prop.	-	25	-	-
Black powder	-	-	0.1	6-8

At PML-TNO we have found 3-7 weight % NO_x for TNT and 2-3 weight % for a Single Base Propellant; it is obvious that the reaction largely depends on the conditions in the furnace.

In the Netherlands the gaseous exhaust products should fulfil the following limits:

Table 4. Dutch threshold values for exhaust gases

Component	Threshold (mg/m^3)
Total solid dust	5
HCl	10
CO	50
SO_x	40
NO_x	70
Heavy metals	1
Cd/Hg	0.05
PCDs (dioxines)	0.1 nanogr. TEQ/m^3

Removal of CO/C_xH_y

This can be achieved by the correct functioning of the afterburner section: temperature above 850 °C, percentage of oxygen above 6 vol %, residence time more than 2 seconds.

Removal of NO_x

By careful design of the furnace burners and the use of clean fuels such as natural gas, the excess formation of NO_x caused by the reaction between N_2 and O_2 can be suppressed. Furthermore NO_x can be decomposed using catalysts. This is most easily achieved in the fluidized bed furnace. Other possibilities are the chemical binding of NO_x with NH_3 and the wet scrubbing technique.

Removal of HCl, SO_x

This can be done by using a wet scrubber in combination with a chemical scrubber (Na_2CO_3).

Removal of dioxines

During the combustion processes of explosives, all the necessary conditions are present for the formation of dioxines. Suitable techniques for the removal of dioxines are: injection of active carbon together with CaO, and the use of active carbon filters (see reference 7).

7. Cost estimate for complete design

The following calculations were made for the situation in the Netherlands (based on the annual figures given in tables 1 and 2), all prices in K fl.

Table 5. Cost calculations

Element	Fluidized bed	Rotary retort furnace
	1000	4500
Water jet cutting	220	220
Mill for fireworks and small calibre	100	
Control apparatus	300	150
Scrubber (wet)	175	175
Denox (chem)	50	50
Dioxine filter	50	50
Site preparation	1155	1355
Total cost	3050	6500

The investment cost of the furnace dominates the total cost; the fixed capacity of the rotary retort exceeds the annual Dutch need many times, whereas the fluidized bed furnace can be tailored to the actual needs.
For the fluidized bed the annual exploitation costs are calculated at 1000 K fl.

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